

ELECTROSTATIC CHARGING OF SALTATING PARTICLES. S. J. Desch¹ and G. R. Wilson², ¹University of Illinois, Department of Physics, 1110 W. Green St., Urbana, IL 61801 (desch@astro.uiuc.edu), ²Arizona State University, Department of Geology at NASA Ames Research Center, MS 242-6, Moffett Field, CA 94035 (gwilson@humbabe.arc.nasa.gov).

Introduction: Dust particles undergoing saltation are charged by a poorly understood mechanism. In this summary, we present a model describing the electrostatic charging of saltation particles. The observations constraining this process are discussed. The physical basis of the hypothesized charging mechanism is outlined. The implications for aeolian processes such as mass transport and abrasion rates are explored.

Observations: Saltating sand particles have long been known to exhibit electric charge [1]. The means by which these particles are charged, however, remains a mystery. The charging mechanism is associated with the rubbing of particles past each other [2, 3]. This process is size-dependent; generally, large sand particles are on average positively charged, and small particles negatively charged. Under conditions typical of terrestrial dust storms, the crossover size was $D_p = 60\mu\text{m}$ [4]. Particles of a given size exhibit both polarities of charge [5]. Large electric fields are associated with particle saltation; during a Montana dust storm, upward-oriented fields with strengths in excess of 150,000 V/m were reported [6]. The total charge of particles collected during the same storm, divided by their mass, was $+60\mu\text{C/kg}$. A comparison of the implied electric and gravitational forces shows that they are comparable. The polarity of the electric field and particle charges is a function of composition. Similar observations of snow blizzards yielded downward electric fields and charge-to-mass ratios of $-10\mu\text{C/kg}$ [7].

These observations of the charging of saltating particles are supplemented by the laboratory experiments of Kunkel [8], in which quartz and other powders were blown off of various substances. The charge and size of individual particles within the resultant dust cloud were simultaneously measured. When quartz powder was blown off of a platinum surface, the particles acquired negative charge. The average charge of particles of size a was found to be proportional to a . Particles of size a had charges distributed about this mean, with a dispersion also roughly proportional to a . Kunkel attributed the dispersion to random contact charging between adjacent dust particles upon launch due to fracturing of crystal surfaces. The mean charge was observed to depend on composition. For quartz powder blown off of quartz, for example, the mean charge was zero.

Model: Incorporating Kunkel's empirical results, we present here a physical model seeking to qualitatively explain the observations of saltating particles. An important component of this model is the contact potential that exists between two materials (usually metals) brought in contact with each other, as illustrated in Figure 1.

This contact potential is the property that determines the placement of a substance on the triboelectric series [9, 10].

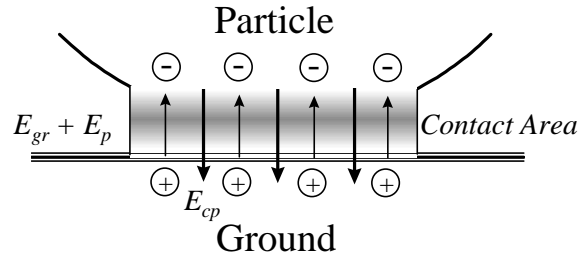


Figure 1. Contact potential illustration.

Charge within the contact region between particle and ground will move only if the electric field,

$$E = (\sigma_g - \sigma_p) / \epsilon_0 - E_{cp} \quad [1]$$

is nonzero. Here, σ_g and σ_p are, respectively, the surface charge densities within the contact region on the ground and particle, ϵ_0 is the permittivity of free space, and $E_{cp} > 0$ is a semi-empirical term meant to represent the effects of the electric field due to a contact potential. The sign of E_{cp} is chosen to reflect the robust result that, for a variety of surface materials, quartz powder is negatively charged by contact [8, 9]. The strength of this electric field is assumed to be a function of particle size. The magnitude of E_{cp} is found by setting $E = 0$, with the condition that the particle interact with only its patch of ground: $E_{cp} = -(2/\epsilon_0) Q_{p,init} / (C.A.)$, where $Q_{p,init}$ is the mean charge on particles of size a and $(C.A.)$ is the contact area. Assuming that $(C.A.)$ is a fixed fraction of the surface area (S.A.) yields, upon application to the results of Kunkel, $E_{cp} \sim 0.3\text{V}/a$ for quartz powder blown off of platinum. All particles are charged to the same voltage. For quartz powder blown off of quartz, $E_{cp} \approx 0$.

Unlike the particles in the dust cloud in Kunkel's experiment, particles undergoing saltation will have repeated contact with the ground. This will alter the charge distribution on the ground and on the particles. A steady-state solution exists. To solve for the charges of ground and particles, we set $E = 0$ above and use the same E_{cp} since it is a function of composition, not charge. The steady-state mean charge on particles of size a is changed from $Q_{p,init}$ to:

$$Q'_p(a) = 2 \left(\frac{S.A.}{C.A.} \right) \left\{ Q_{p,init}(a) - \frac{R}{1+R} \frac{(S.A.)}{<S.A.>} <Q_{p,init}> \right\} \quad [2]$$

where $<>$ denotes a number average over all particles. The quantity R is the ratio of total particle surface area to ground surface area. If only one layer of particles on the surface is active, $R \sim 4$.

Noting that all particles are initially negative, the first term in the brackets above is negative and proportional to a [8], while the second term is positive and proportional to a^2 .

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For large particles, the second term dominates, and they are positively charged, while small particles remain negative. The qualitative effect of a particle size distribution is evident from this equation. If all particles shared the same radius, then the charge and surface area of each particle would equal the average charge and surface area, and the charge on each particle would be small. As a wider range of particle sizes is introduced, it is found that the largest particles can acquire significant positive charge. A net positive charge resides on the ground yielding an upward electric field of strength.

$$E'_{gr} = -\frac{2}{\epsilon_0} \left(\frac{S.A.}{C.A.} \right) \frac{R}{1+R} \frac{\langle Q_{p,init} \rangle}{\langle S.A. \rangle} \quad [3]$$

The calculations above refer to mean charges; charges on particles of a given size follow a normal distribution about these means due to random charging events as observed by Kunkel.

Applications: Having developed a simple physical model to describe the charging of saltating particles, we outline two avenues of research likely to benefit from its predictive power. One long-standing problem is the correlation of particle flux carried by wind with the size distribution of the particles. For a distribution of particles with a wide range of radii, the transport rate can be as much as double the rate for a distribution of particles with the same radii [11], even though the average particle diameter is the same in both distributions. Bagnold attributes this to a more energetic launching of particles. If launch velocities are affected by repulsive electric forces—as observations suggest [6]—then qualitatively a size distribution would increase transport rates by increasing the positive charge on large particles (see Equation 2). A second mystery involves the abrasion rates of rock on Mars. The presence of insignificantly eroded ancient craters on the Martian surface implies abrasion rates much lower than expected, given the wind speeds, composition, etc. on Mars [12]. Greeley et al.

attribute this to a protective veneer formed by clinging of dust aggregates to rock surfaces by electrostatic forces. This is a natural consequence of our model, in which very small particles below some uncertain radius adhere to the positively charged surfaces. In addition, large positive particles responsible for most of the abrasion are repulsed by the ground on impact, reducing their kinetic energy. Further work clarifying and quantifying these issues is planned.

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